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BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

Project	Date	Author

TITLE

APPARATUS FOR MEASURING MOISTURE TENSION AND RESIN EXUDATION PRESSURE IN TREES

By

Robert Z. Callahan
Biological Aid

Forest Insect Laboratory
29 Forestry Bldg., U. C.
Berkeley 4, California
January 31, 1952

SUBJECT—

INDEX NO.—

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Forest Insect Laboratory
29 Forestry Bldg., U. C.
Berkeley 4, California

February 20, 1952

To: Dr. J. A. Beal, in Charge, Forest Insect Investigations, Beltsville, Maryland

From: F. P. Keen, in Charge, Berkeley Forest Insect Laboratory

Subject: Report by Callaham "Apparatus for measuring moisture tension and resin exudation pressure in trees"

Callaham has the theory that resistance of trees to bark beetles may be due to (1) the toxic effect of certain oleoresins, or (2) the exudation pressure and moisture tension which condition the resistance of the tree to attempted beetle attack. In order to test the second theory he attempted to set up an apparatus to measure resin pressure but ran into considerable difficulty, particularly in getting a tight seal and trying to avoid clogging of tubes. It was only after a consultation with MacDougal that he succeeded in perfecting an apparatus along the lines of MacDougal's earlier experience. This work is described in the accompanying progress report.

Now that a method of measuring moisture tension has been developed, it is proposed to measure such tension in a series of high risk and low risk trees and those recently attacked to see whether the moisture tension theory has merit. This he proposes to do during the coming field season.

Enclosure

Forest Insect Laboratory
29 Forestry Bldg., U. C.
Berkeley 4, California

February 25, 1952

Mr. C. S. Schopmeyer
S. E. Forest Experiment Station
Post Office Building
Lake City, Florida

Dear Mr. Schopmeyer:

Enclosed is a copy of the report which I mentioned in my letter of December 7, 1951 concerning the apparatus for measuring moisture tension and oleoresin exudation pressure in pines. You will note that this is a report merely of the development of the apparatus and not of its actual application. We hope to use this apparatus in tests this coming field season to investigate the role of these factors in the resistance of pines to bark beetles. If you wish, we will send you any information on the results of these experiments at the end of the field season.

In response to your letter of November 23, 1951, I would like to say that I was very much interested in your findings with regard to the relation between the rate of resin flow and the modification of Poiseuille's law. If I can find the time this summer, I hope to investigate in a series of trees of different beetle susceptibility the three factors which you found so significant. As to your opinion that the effect of moisture tension on the resin production of different trees would be equal on a given site, I think that this is undoubtedly true if each tree has the same capacity for utilization of the ground water. Obviously, trees with different crown shape, size, density, etc. (transpiration capacity) and different root development (water in-take capacity) may show differences in water economy and moisture tension. It is this type of problem with which we are particularly concerned; that is, trees with different physiographic characteristics show different susceptibilities to insects, and it is my opinion that this condition may be related to the resin production capacity which Ivanov and Munsch showed was related in part to moisture supply in the xylem.

I mentioned Poiseuille's law above, but as yet I have not been able to find where it is published. I would appreciate reference to this if you can supply it.

I have recently prepared a rough draft of a report on the factors of resin production and their possible role in susceptibility of trees to bark beetles. There is nothing new in this, but I will send a copy to you for your comments and criticism when it is finished.

Very truly yours,

F. P. Keen, in Charge

By: Robert Z. Callaham
Biological Aid

Enclosure

cc: Dr. Beal

Forest Insect Laboratory
29 Forestry Bldg., U. C.
Berkeley 4, California

February 26, 1952

Dr. D. T. MacDougal
Route 170
Carmel, California

Dear Dr. MacDougal:

Enclosed is a copy of the report of my work which I mentioned to you during our visit. The final apparatus developed is essentially the one which you used with only slight modifications. It is our hope that we will be able to use this apparatus in extensive tests this coming field season to investigate the role of moisture tension and resin exudation pressure in the susceptibility of ponderosa pine to bark beetles.

I want to thank you again for the information and equipment which you so generously gave me on the occasion of our visit.

Sincerely yours,

F. P. Keen, in Charge

By: Robert Z. Callaham
Biological Aid

Enclosure

Forest Insect Laboratory
29 Forestry Bldg., U. C.
Berkeley 4, California

February 21, 1952

To: Institute of Forest Genetics, Placerville, Calif.
(Through: S. N. Wyckoff, Director, CF&RES)

From: F. P. Keen, in Charge, Forest Insect Laboratory, Berkeley

Subject: Callaham's Report "Apparatus for measuring moisture tension and resin exudation pressure in trees"

Enclosed is a copy of Callaham's report pertaining to one phase of the work which he conducted during his assignment at the Institute of Forest Genetics last season. His first attempts to develop a manometer for measuring resin exudation pressure and moisture tension in pines were unsuccessful, but with the aid of the staff and facilities of the Institute he finally was able to develop an apparatus for making such measurements. It is Callaham's opinion that these factors of resin exudation pressure and moisture tension play a key role in determining the susceptibility of pines to bark-beetle attacks and we hope that the validity of this theory can be investigated on a rather extensive scale during the coming season by the use of the manometers discussed in this report.

Enclosure

APPARATUS FOR MEASURING MOISTURE TENSION AND RESIN EXUDATION PRESSURE IN TREES

Submitted by:

Robert Z. Callaham
Biological Aid

Approved by:

F. P. Keen
Entomologist in Charge

Forest Insect Laboratory
29 Forestry Bldg., U. C.
Berkeley 4, California
January 31, 1952

APPARATUS FOR MEASURING MOISTURE TENSION AND RESIN EXUDATION PRESSURE IN TREES

There has been a great deal of contradictory discussion in the literature over the past years as to the significance of the moisture content of various tissues of trees as an indicator of the resistance or susceptibility of trees to insect attack. The usual sampling method, that of determining moisture content on a dry or wet weight basis, has been criticized time and again as not depicting the true moisture conditions in the tree. For example, it does not take into consideration the water economy of the tree, the rate of movement of water in the tree, or other important host-water relationships.

Recent correspondence to the author with W. L. Baker, Assistant to the Chief, Division of Forest Insect Investigations, points quite well to the perplexing situation which presents itself at the present time. He writes:

> "I have often wondered if a true comparison is made between moisture contents of two trees, one having a small amount of foliage and the other a large amount, or one growing under drought conditions and the other under adequate moisture conditions, by the usual methods of sampling. I wonder if the whole story is told simply by going into any one of these trees at any one time and measuring the moisture content as of the moment. I keep thinking of the water in a tree as a sort of stream -- not as a sort of pool. Now you can take a bucket and lift a gallon of water from a stream and also one from a pool. When you have done this, however, you have by no means sampled the amount of water passing the points of removal during a day. I am wondering if there is any significance in the amount of water that passes any given point on the trunk of a tree during some given period of time . . . ."

Similar questions also have occupied the thoughts of many individuals, particularly with respect to understanding the problems of the host-water relationship of pines which are attacked and killed by bark beetles. The usual dry-weight, moisture sampling methods have been utilized in attempts to analyze the moisture conditions of pines both of different age and vigor classes and also of different degrees of susceptibility to bark beetles (Beal, 1931) (Hall, 1949) (Struble, 1949) (Callaham, 1951). However, the results obtained by these methods have been very erratic and contradictory, and they do not indicate that moisture quantity per unit volume of wood has any relation to beetle susceptibility. An alternative possibility, however, is that the physical conditions of the tree's moisture column may be related in some way to this beetle susceptibility.

If a satisfactory method could be developed for measuring these conditions, then it should be possible through field tests to determine whether or not moisture tension is related to the susceptibility of pines to bark beetles. With this in mind an attempt was made during the 1951 field season to develop a suitable technique for making continuous observations of the moisture tensions within the hydrostatic systems of pines, and it is the purpose of this report to present the results of this work.

History of Investigations

An extensive review of the literature pertaining to these techniques will not be attempted in this report. However, it should be pointed out that Crafts, Currier, and Stocking (1949, pp. 162-167) discuss in some detail the methods of direct measurement of moisture tensions in the xylem.

The methods presented are those which have been used to determine exactly the actual, internal tensions at a given time. In general, all of these methods involve tedious laboratory techniques which are not applicable for use on forest trees. In addition, they result in permanent injury to the tissues. Thus, these conditions make it impossible to use any of these methods where a continuous, or long-term, series of observations are to be made on a single individual.

However, the method developed by MacDougal (1926), which is not discussed in Crafts et al., makes possible such observations with no deleterious effects upon the individual being studied. The primary objection to using MacDougal's method is that it requires that the hydrostatic system of the tree be opened at some point with a resulting alteration of the original conditions of tension. However, if the method is used to study the relative change in conditions over a long period of time, and not the original conditions within the tree, then the objections to the method become relatively insignificant, and the method can be used very satisfactorily to provide a usable index of moisture tension.

A second criticism of the method is that duplicate set-ups can never be made on one or more trees because of (1) the nature of the hydrostatic system of pines, and (2) the inaccuracy of determining the depth and direction of the bore holes. However, if care is taken in making the bore holes and if these factors are considered in all analyses of moisture tension data, then the method still can contribute a great deal to our understandings of the host-water relations of pines which are attacked and killed by bark beetles.

Discussion of 1951 Studies

This report deals primarily with the adaptation and modification of MacDougal's technique for use on the bark-beetle problem. However, before this technique was brought to the attention of the author, several unsuccessful attempts had been made to perfect a moisture tension apparatus. A discussion of these unsuccessful efforts is included first in this report because they point out some of the difficulties which are to be encountered in using moisture tension apparatus.

Unsuccessful Techniques -

These techniques were based on the design of a successful model which had been constructed in the laboratory. The method used in this technique was to drill a slanting, tangential bore-hole completely through the tree. The lower end of this was to be fitted with a sealed water-filled vessel to collect the oleoresin which would drain from the bore-hole under the influence of gravity. The upper end of the bore-hole was to be connected by a fitting to a piece of capillary glass tubing which was standing in an open dish of mercury. This arrangement, with respect to the bore-hole, was used because previous experiments on tree injection, which were carried out by the Berkeley laboratory, had shown that the clogging effect of oleoresin on bore-holes could be overcome by providing a gravity drain for the solid material.

The difficulties encountered with this apparatus were numerous and are listed below:

(1) Drilling the tangential bore-hole with a brace and bit is an extremely difficult and inaccurate method. The resulting hole usually is not as clean sided as it should be, and any wood fragments remaining

in the bore-hole tend to clog the hole as resin collects. In addition, these fragments tend to trap any air bubbles released from the central gaseous cylinder, and this tends to alter the readings of the manometer. It was found that these difficulties could be surmounted best by using a Swedish increment borer of large diameter.

(2) The oleoresin would not drain out of the first tangential bore-holes into the closed vessel because the water caused it to solidify at the point of exudation. This made it impossible to remove air bubbles from the central gaseous cylinder which entered the bore-hole. Eventually the oleoresin clogged the entire length of the bore-hole. It is very difficult to clean the oleoresin out of the bore-hole with a brace and bit, but by using an increment borer the hole can be rapidly and easily cleaned.

(3) Considerable difficulty was encountered in trying to seal the ends of the bore-hole. The apparatus used was a small, 1-1/2 inch, tin, jar lid to which a metal pipe shank had been soldered. An expansion bit, slightly larger than the lid, was used to bore a hole in the bark and phloem tissues. Then the lid was placed in the opening, and string, which had been dipped in cement, was packed around the edges of the lid to seal it into the tree. However, none of these attempts at sealing were successful because of the succulent and permeable nature of the tissues surrounding the lids.

Various cements were used with the packing to seal the edges of the lids into the tree. These included commercial celloidin, linoleum cement, plumber's litharge (finely ground red lead in glycerine), rapid drying, cellulose-base cement, Canada balsam, and synthetic-resin mounting media (i.e., Clarite, Permount, and Euparol). However, not one of the attempts

was successful and lack of success in sealing the lids in place probably resulted from the technique used rather than from the sealing properties of the cements.

Finally, it was concluded that it would be necessary to use something such as a threaded pipe which could be seated or bored directly into the wood to secure a satisfactory closure of the ends of the bore-hole.

(4) The air which escapes into the bore-hole from the central gaseous cylinder of the tree also causes a great deal of difficulty because it disrupts the manometer readings. However, a great deal of this air escape can be prevented and more reliable readings can be obtained if extreme care is taken to restrict the bore-hole to the outer annual rings in which most of the water transport takes place. Despite all precautions, some air bubbles will be released into the bore-hole, and their removal will be considerably simplified if the bore-holes are slanted downward, rather than being made horizontal. In addition, the connection leading from the bore-hole to the vertical elements of the manometer should all be slanted. This facilitates the rise of the air bubbles to the top of the system where they are released from the manometer.

Successful Techniques (from MacDougal) -

After these unsuccessful techniques had been tried out, MacDougal's work was brought to the attention of the author. It was immediately apparent that his technique provided the means of circumventing all of the problems which had presented themselves in the previous work. The initial trial of his technique resulted in the first successful manometric measurements of the season.

Several other trials were made before the close of the field season, and these indicated that there could be very little improvement on MacDougal's technique. However, one point which is lacking in MacDougal's articles is an adequate description of the techniques of installing his apparatus. Therefore, the following description of his apparatus and techniques with suggested improvements is presented at this time.1/

Bore-holes - In moisture tension work, MacDougal usually drilled the bore holes with a Swedish increment borer which was 0.48 inch in diameter. This method had many advantages: (a) the bore-hole was clean; (b) it did not fill up too rapidly with resin; (c) it allowed fairly large air bubbles to rise into the manometer; (d) it was of uniform diameter; (e) depth could be accurately determined; and (f) the annual rings included in the bore could be readily studied.

The author in his work has observed that surface tensions tend to prevent the movement of air bubbles out of bore-holes of small diameter; thus, with larger diameter bore-holes there would be less clogging of the apparatus and less need for adjustment. However, one must consider that small diameter bore holes definitely are more advantageous for restricting the bore hole to the peripheral, cohesive column of water and for measuring resin exudation pressure. In the case of the latter, they would fill more rapidly with oleoresin and would attain maximum pressures sooner after boring than would larger diameter bore-holes.

1/ This description was obtained from MacDougal's article, and from a personal visit with Dr. MacDougal at his Carmel, Calif. residence, at which time he graciously gave several samples of his threaded tubes (MacDougal, 1926, fig. 8) to the author.

The direction and length of the bore-holes is a very critical matter, and MacDougal (p. 51) discusses the differences between radial and tangential bore-holes. In general, it seems that the most desirable bore-hole for measuring the moisture tension in pines is one which is bored on a tangent through the water conducting layers. Ideally, the bore should penetrate only the annual rings which are actively conducting water to the crown. According to MacDougal (p. 124) and others, in pines these are the annual rings which are actually connected with the leaf-bearing internodes.

Drilling the bore-holes under water to prevent the access of air into the severed tracheary elements was not considered to be necessary by MacDougal. He points out that the water columns in the adjacent unsevered elements are not altered by the boring process and that the moisture tensions measured in the bore-holes will be those of the unsevered adjacent elements. However, if it is desired to bore the holes under water, this can be done very simply by cutting a large section of rubber sheeting from an old inner tube. After the bark has been smoothed with a draw knife or axe, the lower edges of the rubber should be nailed very securely to the tree to form a cup. Next a small hole is made in the center of the rubber sheet, and the rubber cup is filled with water. The increment borer is inserted through the small hole into the tree and the bore-hole is made. When the increment borer is withdrawn with the core, the threaded tube is quickly inserted through the same small hole and screwed into position.

Threaded Tubes - Each of MacDougal's threaded tubes (p. 28) had its particular advantages. However, the tubes shown in Figure 1 are best adapted for moisture tension work. The tapered, threaded tube has to be specially machined, but it has the advantage of giving the best seal of all of the tubes. The tube with standard pipe threads has the advantages of being the cheapest of all and of being available in the great variety of standard pipe sizes. However, there is very little taper to the threads, and this makes the sealing of these tubes a bit more difficult.

Cement - In all cases, MacDougal used Canada balsam as a sealing agent on the threads of the tubes. From the limited experience of the author, this also seems to be the best cementing agent because it is non-water soluble, comparatively slow drying, viscous, and yet it sets fairly well in a day or so.

Manometers - The design of MacDougal's manometers is self-evident from the various figures depicting his experiments. The experience of the author has indicated that 2-3 mm. capillary tubing should be used in their construction, as shown in Figure 2. One point of economy should be noted. If the manometer is constructed in two separate parts, joined by rubber, vacuum tubing (Figure 3), the closed and open arms can be readily interchanged. This facilitates measuring both resin exudation pressure (closed arm) and moisture tension (open arm) without changing the connection between the bore-hole and the manometer.

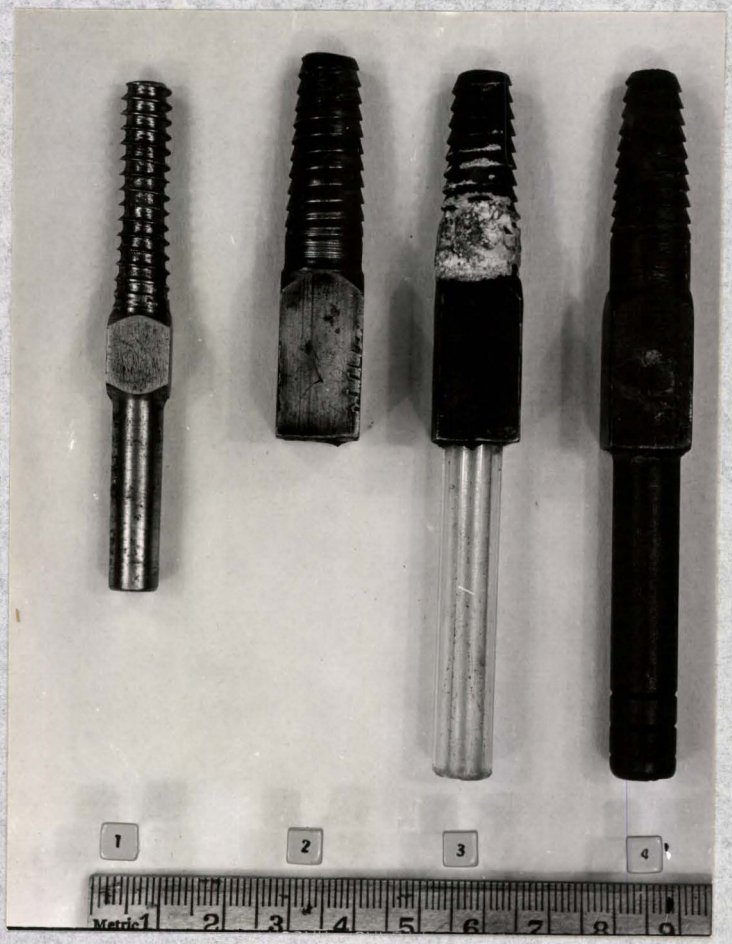

Figure 1. MacDougal's tapered, threaded tubes.

1. Small diameter, 1-piece, steel tube used by MacDougal to restrict the bore to individual rings in transverse sections.
2, 3, & 4. Larger diameter, 2-piece, brass tubes for general manometric connections.
3. Brass, threaded fitting with glass-tubing shank.
4. Brass, threaded fitting with brass-tubing shank.

Figure 2. Manometer installed on a pine, connected by rubber, vacuum tubing to a 1/2-inch pipe nipple which is seated in the bore-hole. The overhead water reservoir is used in filling the bore-hole, pipe and manometer with water.

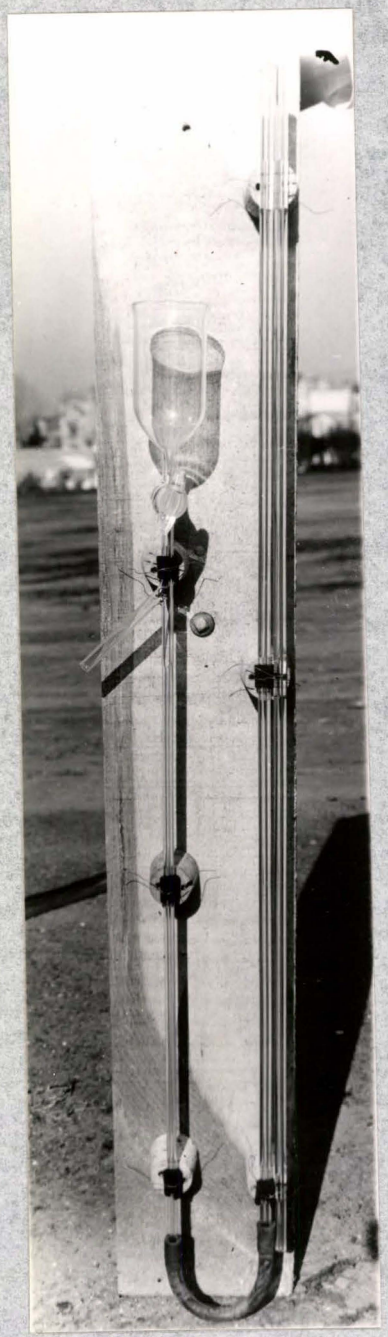

Figure 3. Improved manometer constructed with rubber tubing joining the two sides of the manometer. Interchangeable closed-end and open-end capillary tubes are shown at right. Side arm at left is slanted to facilitate release of air bubbles from the manometer by means of the stopcock and water reservoir.

SUMMARY

The need for a method of measuring the moisture conditions in pines other than the dry weight method is discussed. The author describes his first unsuccessful attempts to develop a technique for measuring moisture tension, and then describes a technique developed by MacDougal. Suggested improvements on this latter technique also are presented.

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